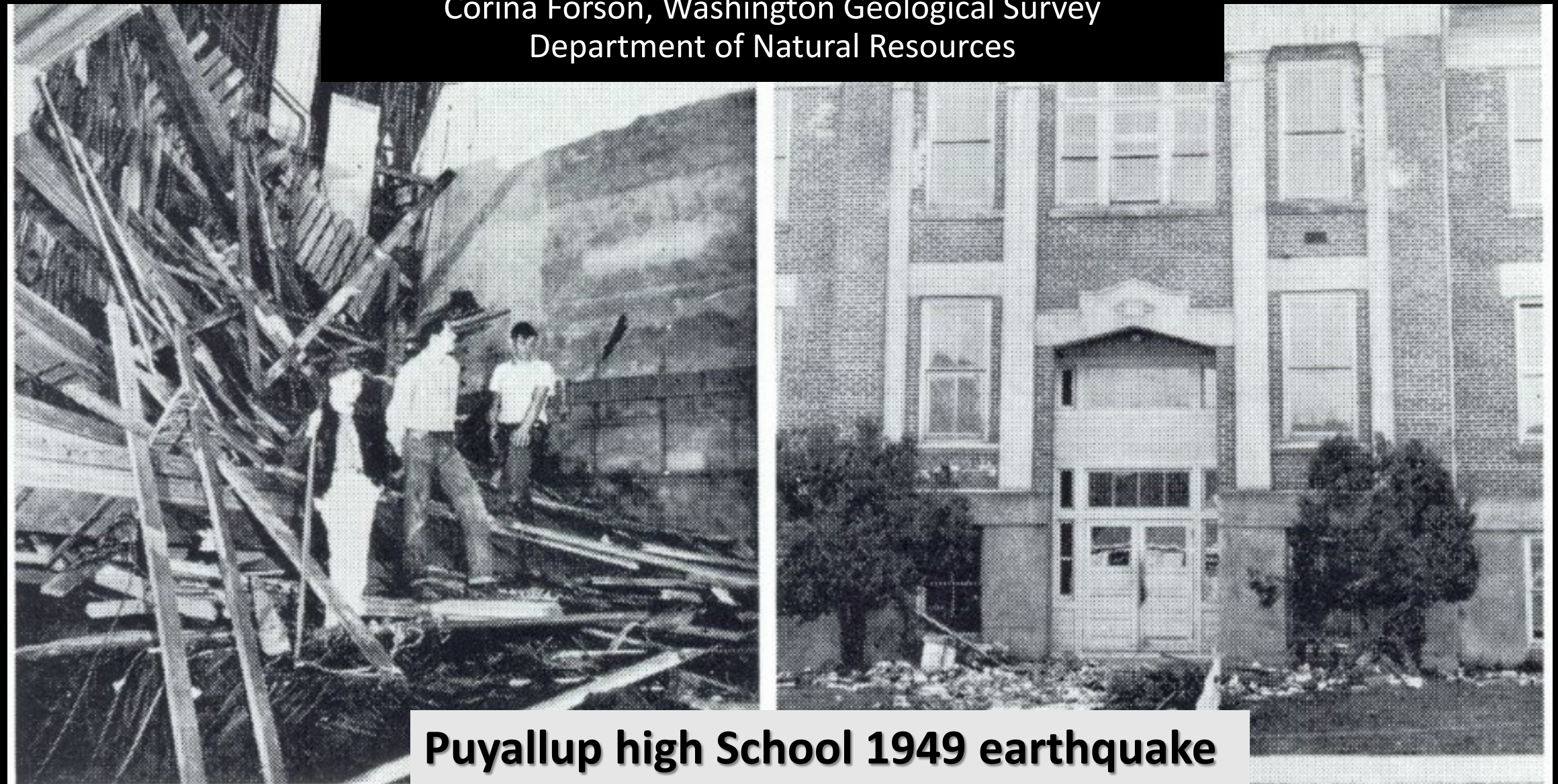
Earthquake Hazards Pierce County

Corina Forson, Washington Geological Survey
Department of Natural Resources

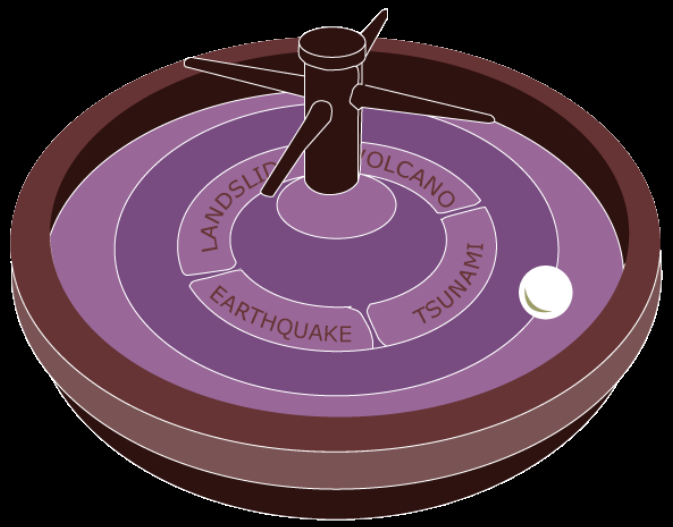


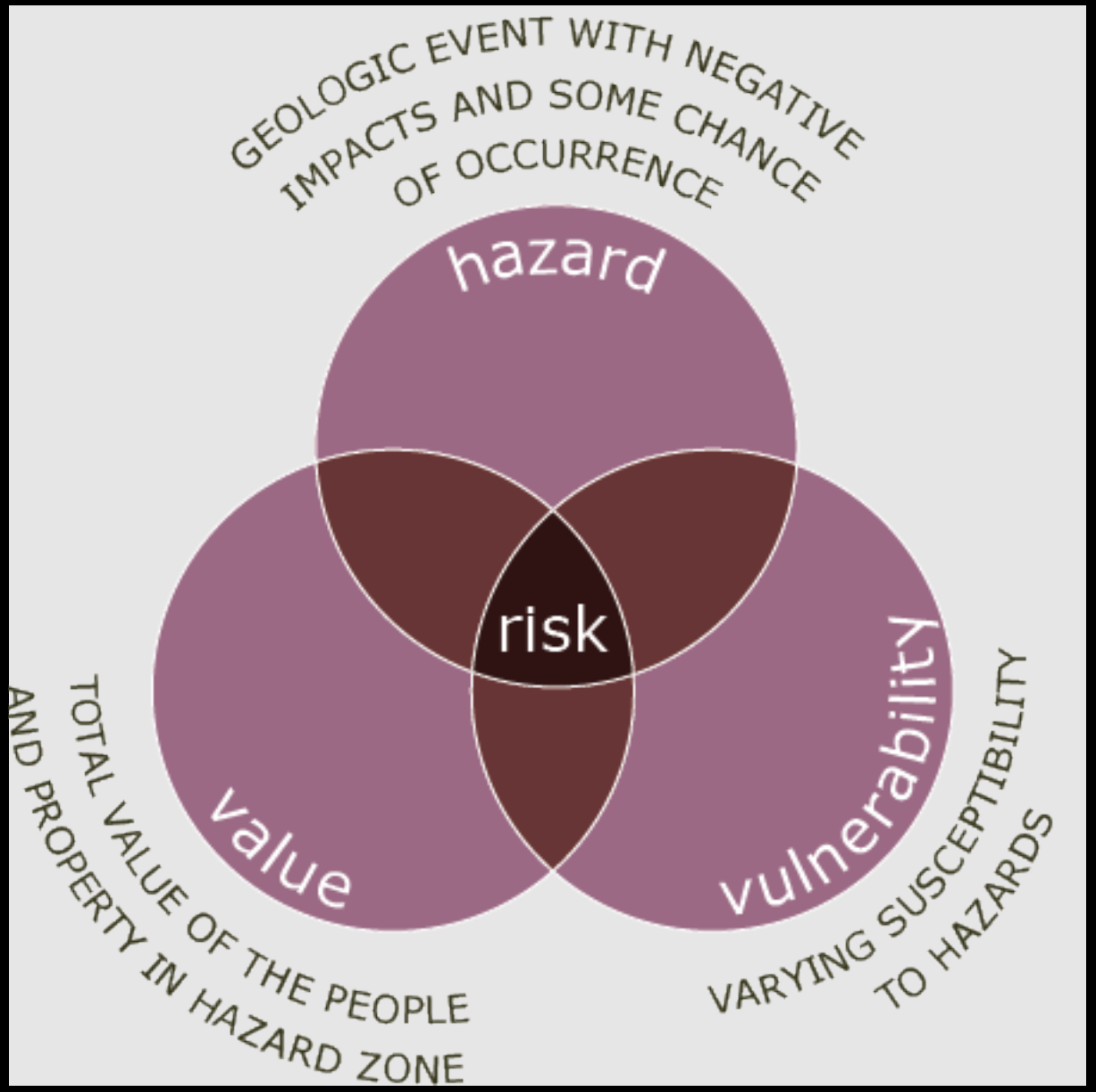
Puyallup high School 1949 earthquake

Geologic Risk

Risk analysis (and one of our biggest jobs) is to try and answer:

- What **hazards** exist?
- What is their **likelihood**?
- What are their **consequences**?

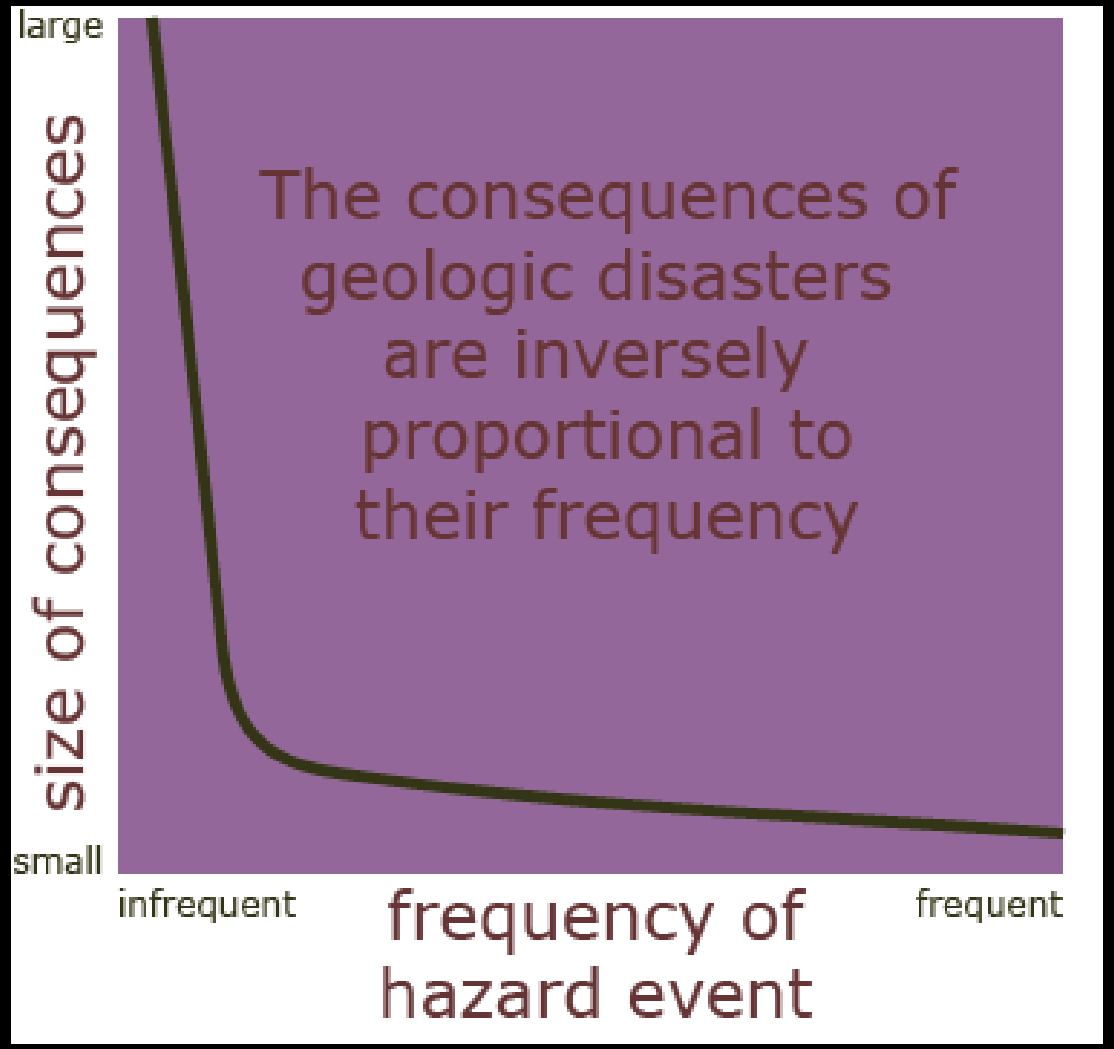




Small events happen **frequently**. Large events are **disastrous** and happen every **few hundred years**.

Knowing **what the hazards are** and **where they occur** is important...

It is equally important to know **how often** they occur.



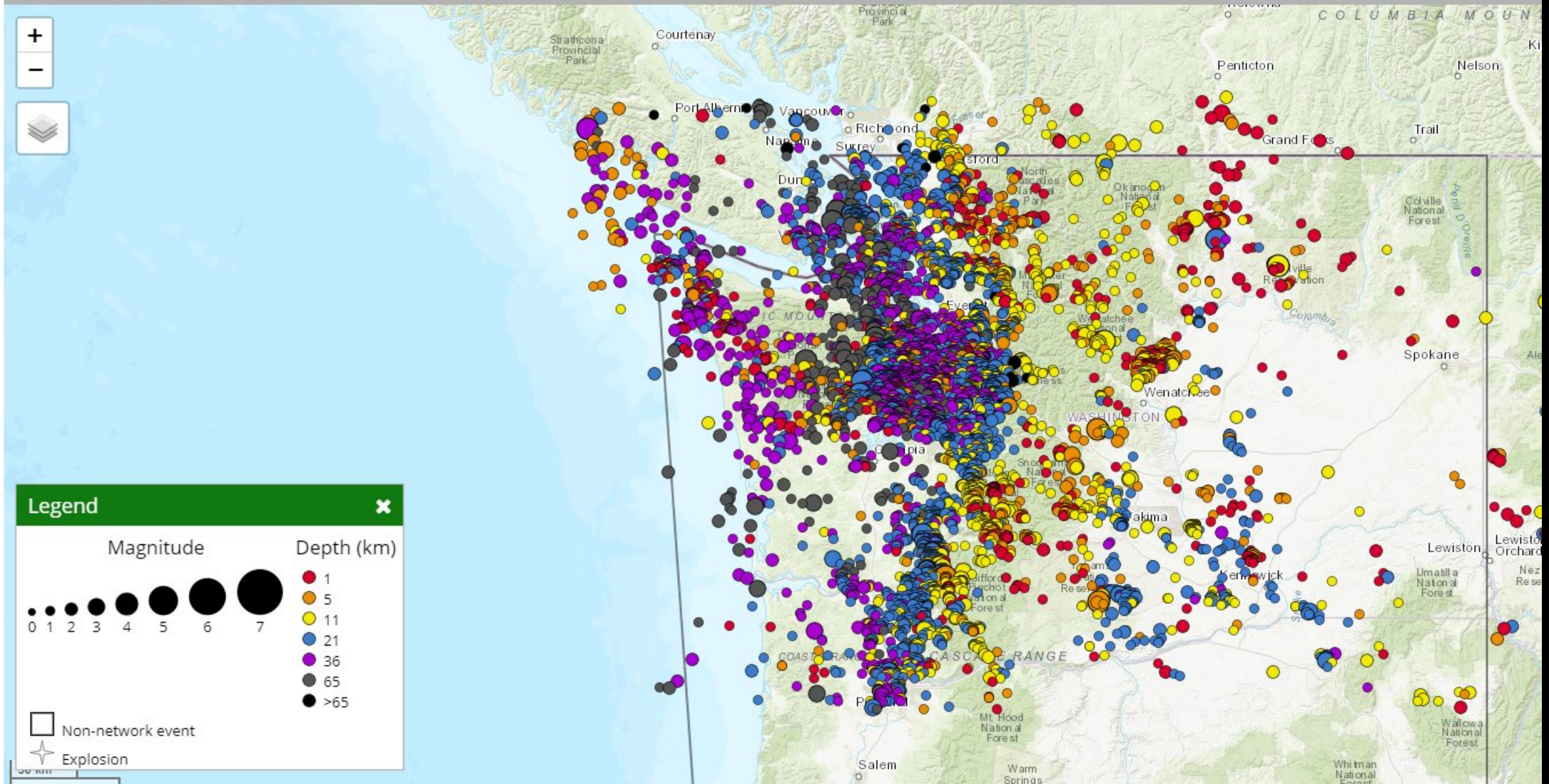
PNSN
Pacific Northwest Seismic Network

Earthquakes Seismograms Volcano Seismicity

> Earthquakes > Custom Map

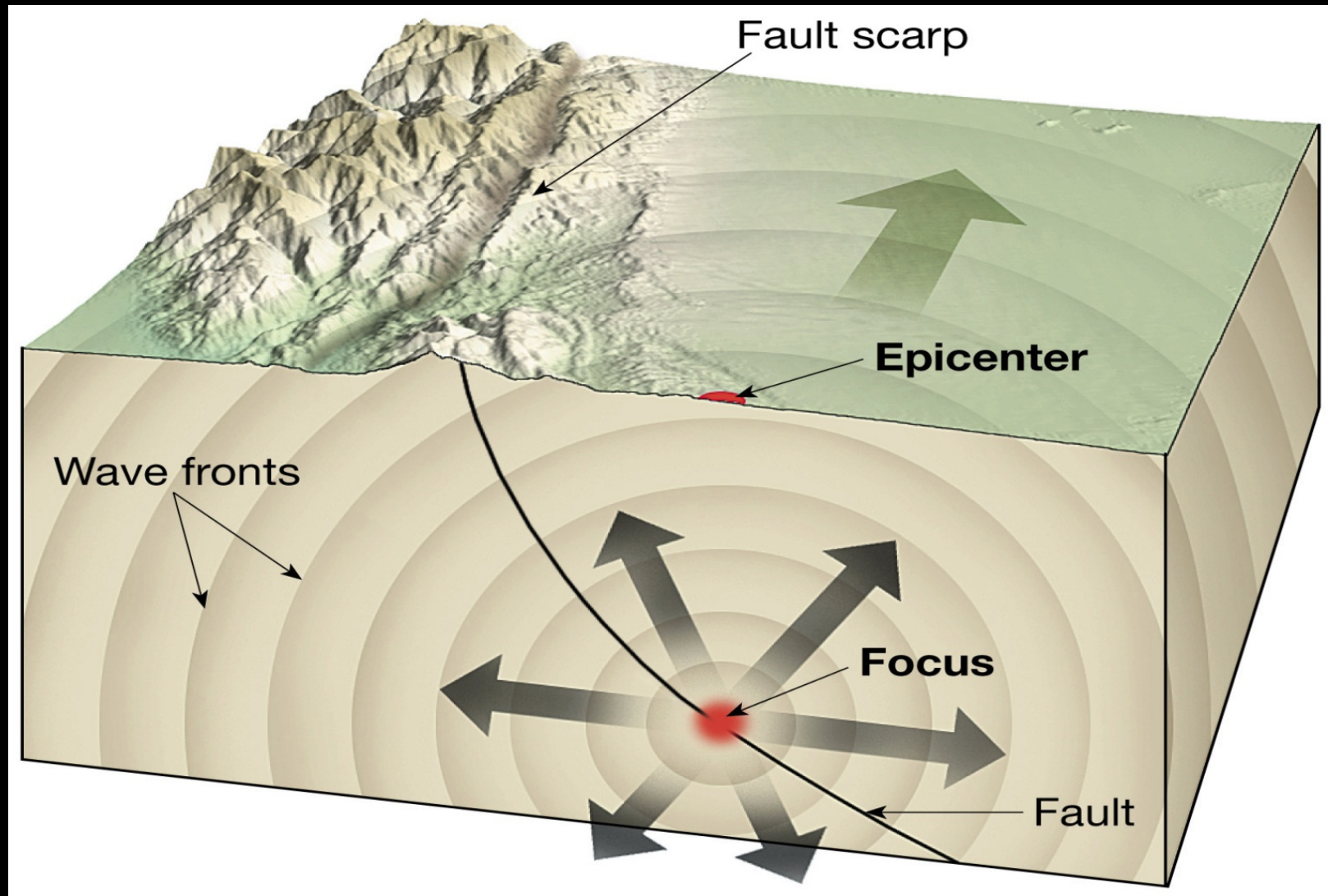
Custom Map

Total: 8537 | **Largest:** 4.8 | **Smallest:** 1.0 | **Latest** 2019/3/1 | **Earliest:** 2010/1/1



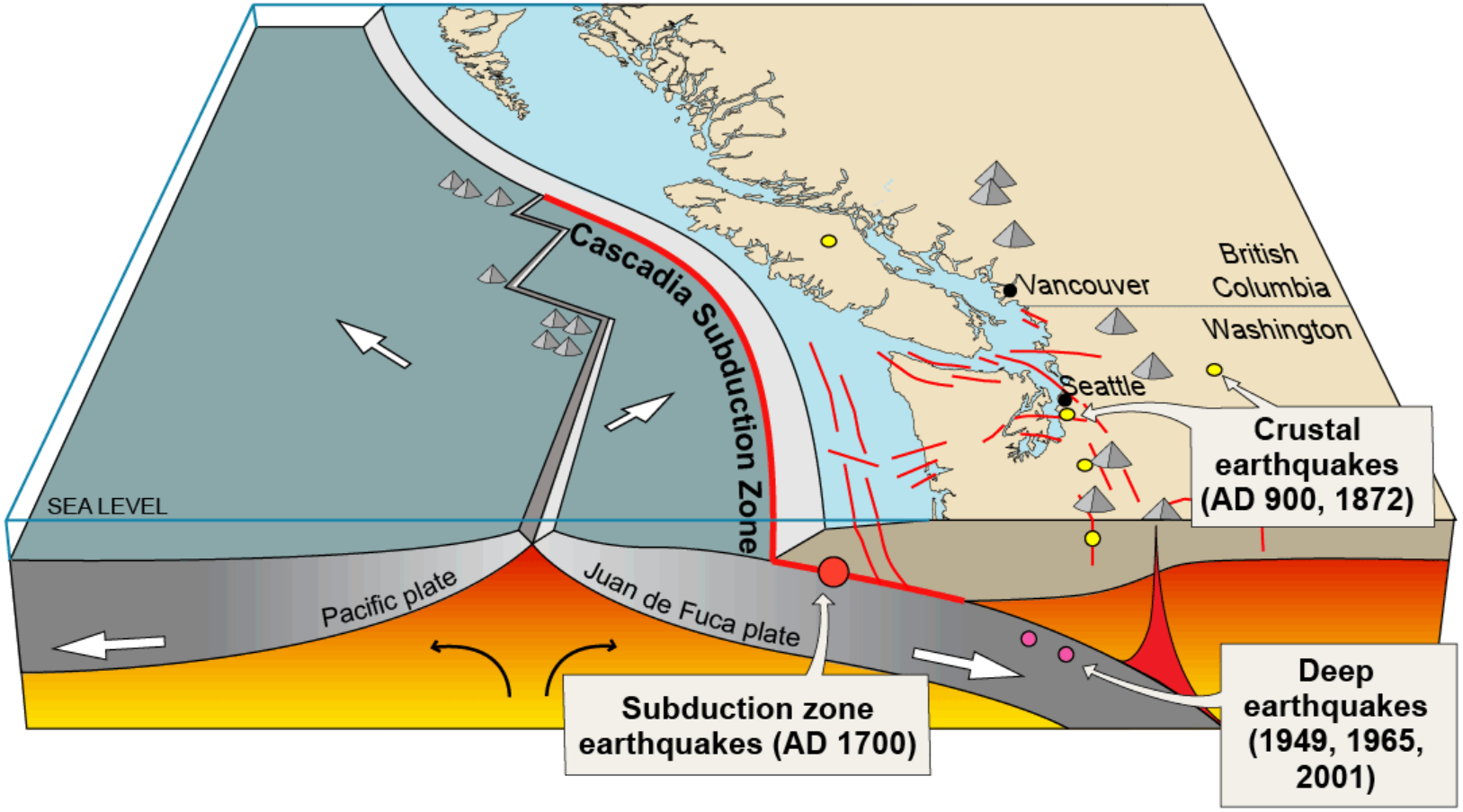
What is an Earthquake?

- An earthquake is the vibration of Earth produced by the rapid release of energy
- Energy released radiates in all directions from its source, the focus
- Energy is in the form of waves
- Sensitive instruments around the world record the event
- Movements that produce earthquakes are usually associated with large fractures in Earth's crust called faults



Fault types

- Dip-slip faults: Vertical motion
- Strike-slip faults: Horizontal motion
- Oblique faults: Combination



Source	Max. Size	Recurrence
Subduction zone	M 9+	200–600 years
Deep Juan de Fuca plate	M 7+	30–50 years
Crustal faults	M 7+	Hundreds of years?

Volcano

Active crustal fault

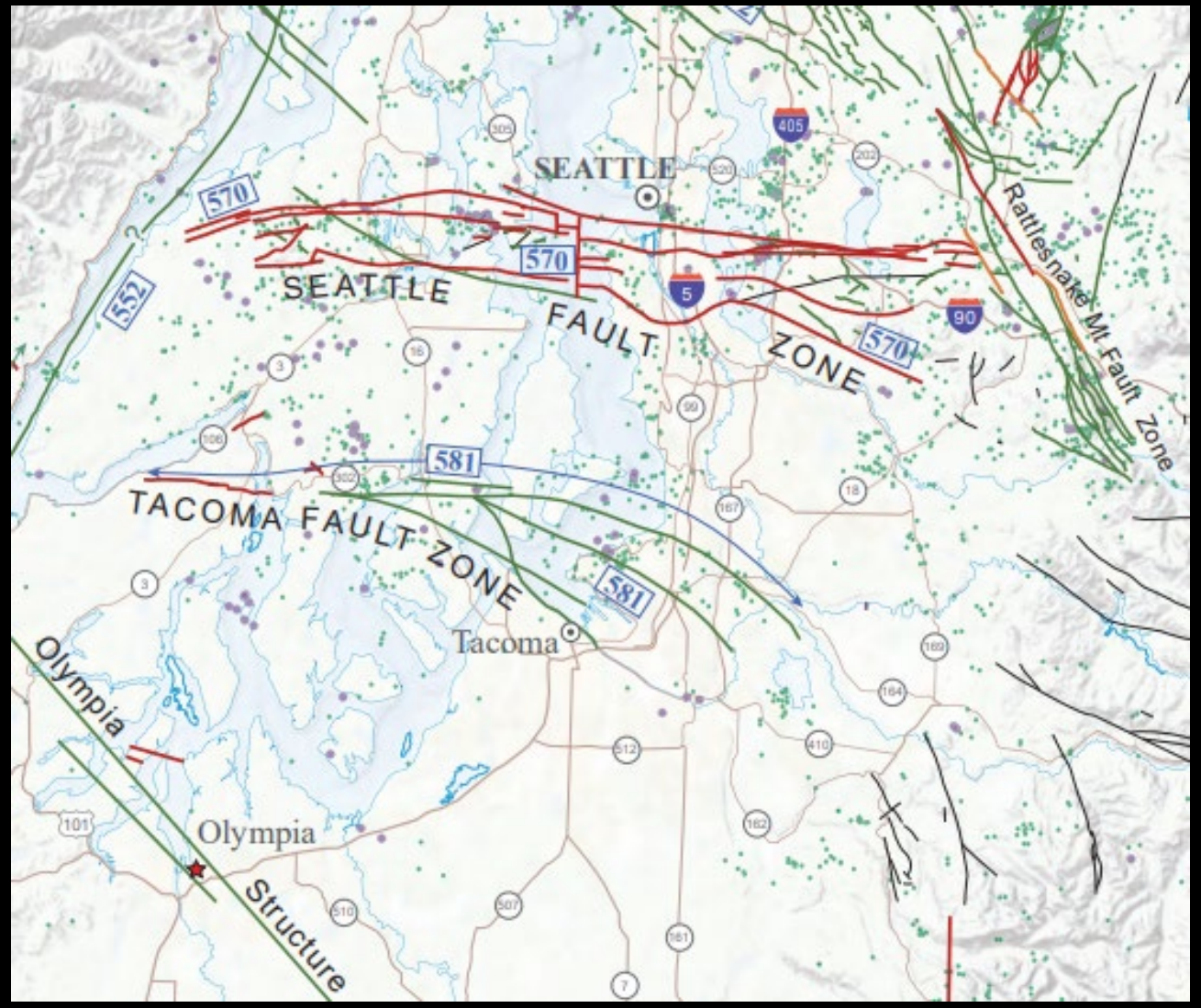
Active plate boundary fault

*figure modified from USGS Cascadia earthquake graphics at http://geomaps.wr.usgs.gov/pacnw/pacnweq/index.html

Pierce County earthquake sources - active faults

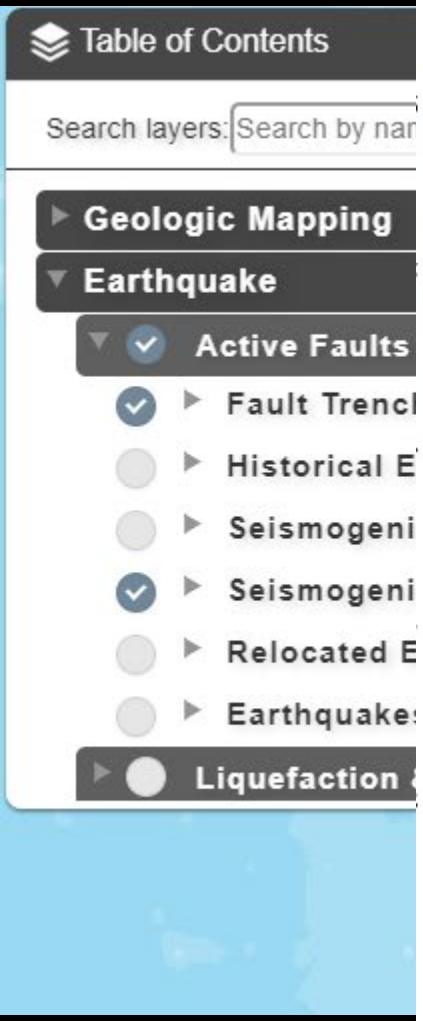
Major faults in your are that could cause damaging earthquakes:

- **<u>Cascadia Subduction Zone,</u>** capable of Magnitude 9+, subduction zone earthquake
- **<u>Deep earthquake (Benioff Zone),</u>** capable of ~M 6-7.5, Nisqually type earthquake
- **<u>Crustal Faults:</u>** Tacoma fault, Seattle Fault, Rattlesnake Mountain Fault zone, Olympia structure, capable of ~M 6-7.5



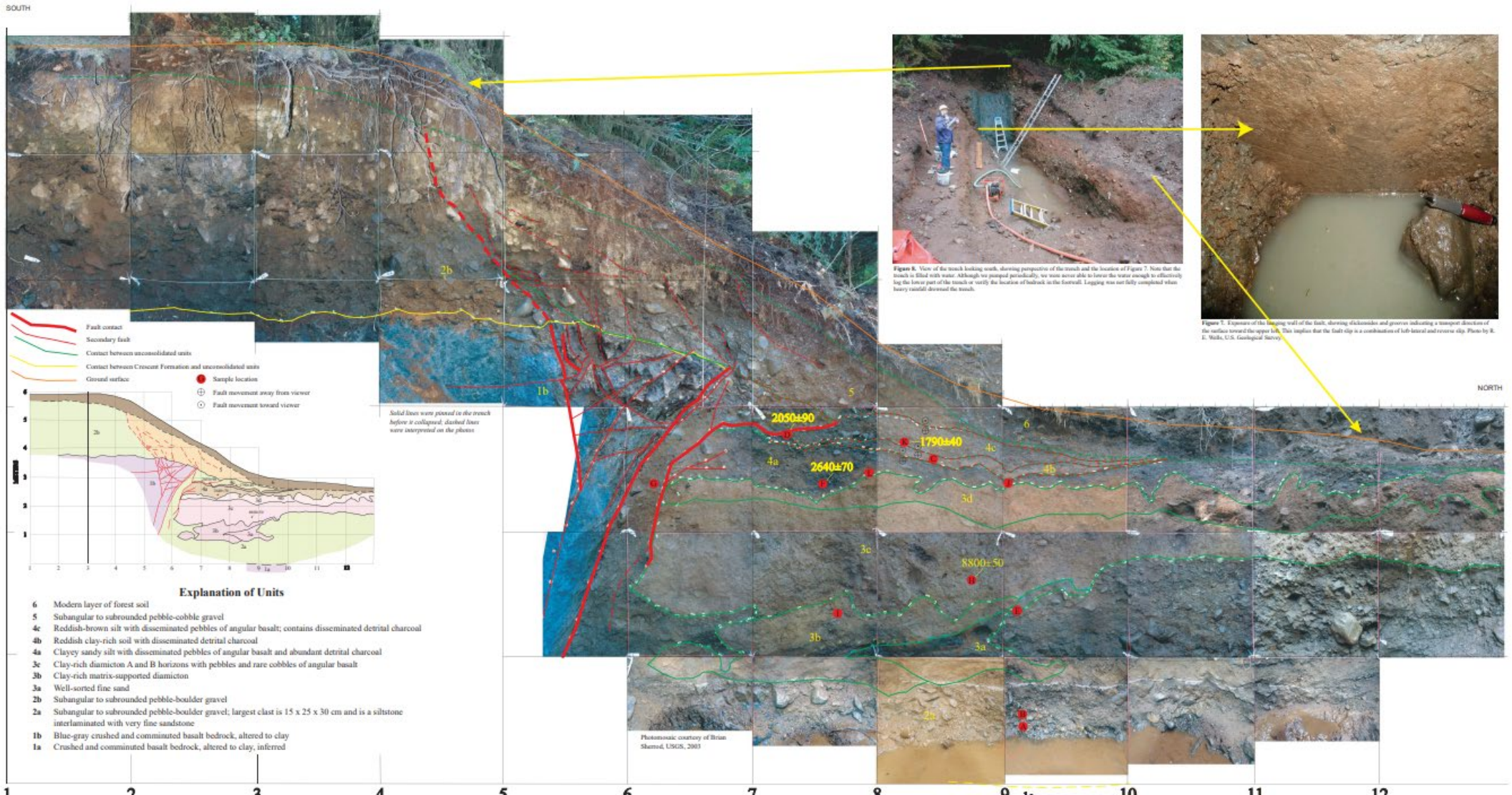
Active faults

Fault trenching tells us about when faults ruptured and their geometry



by Timothy J. Walsh and Robert L. Logan

2007



Mapped faults

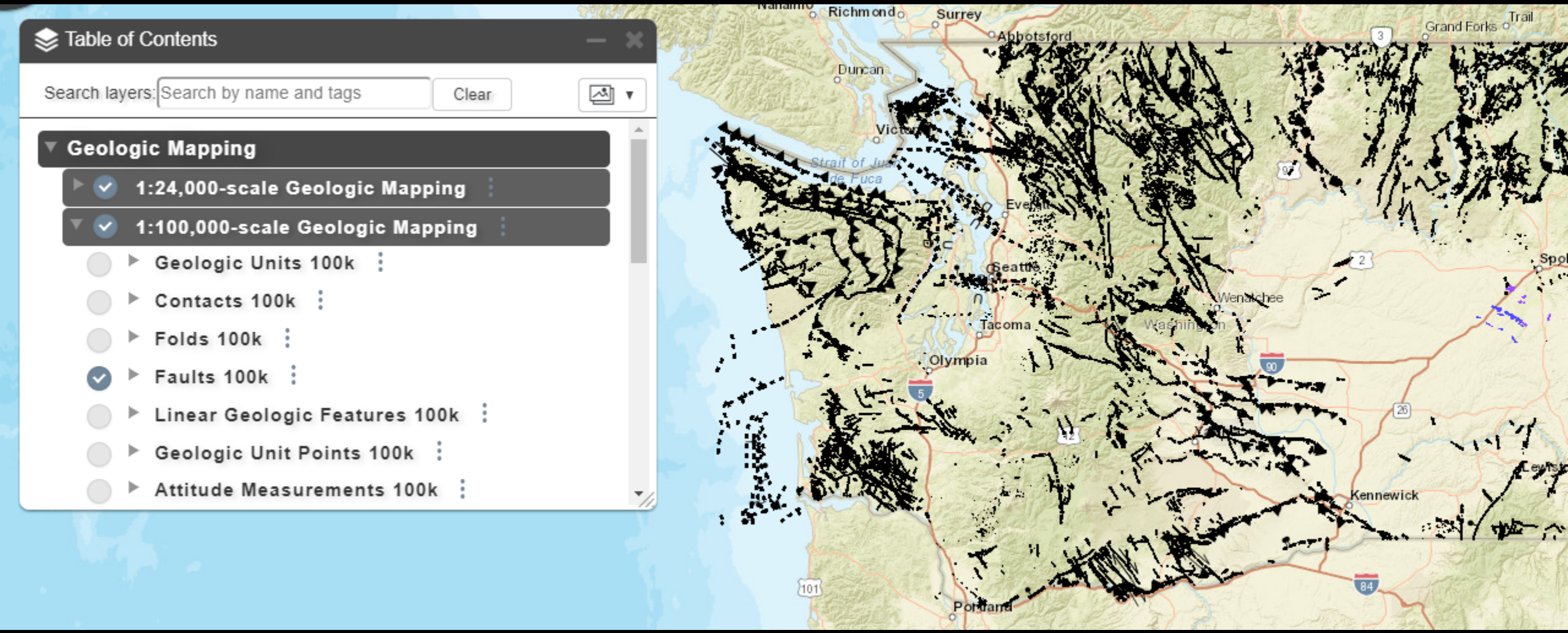
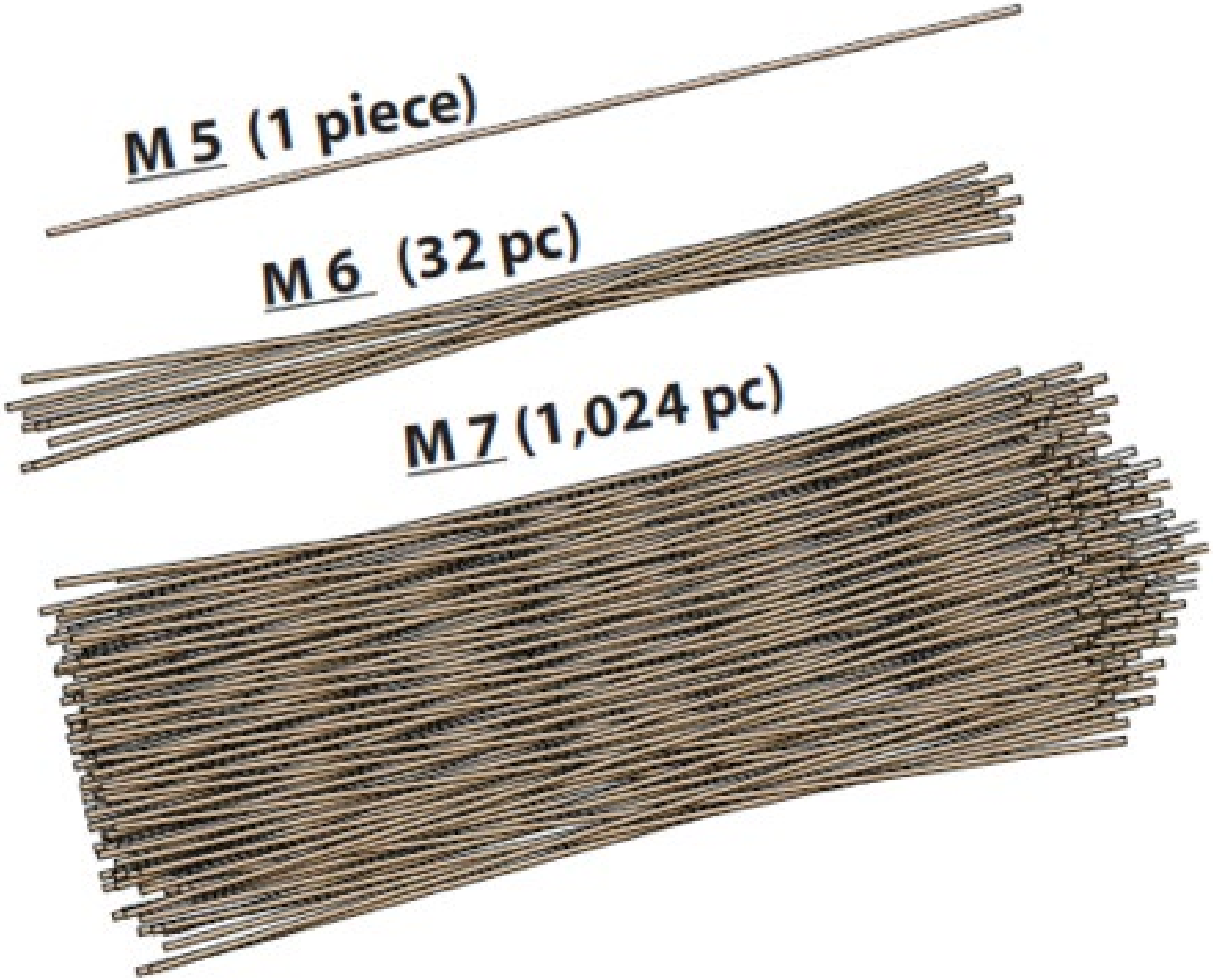


TABLE 16.3 **Earthquake Magn**

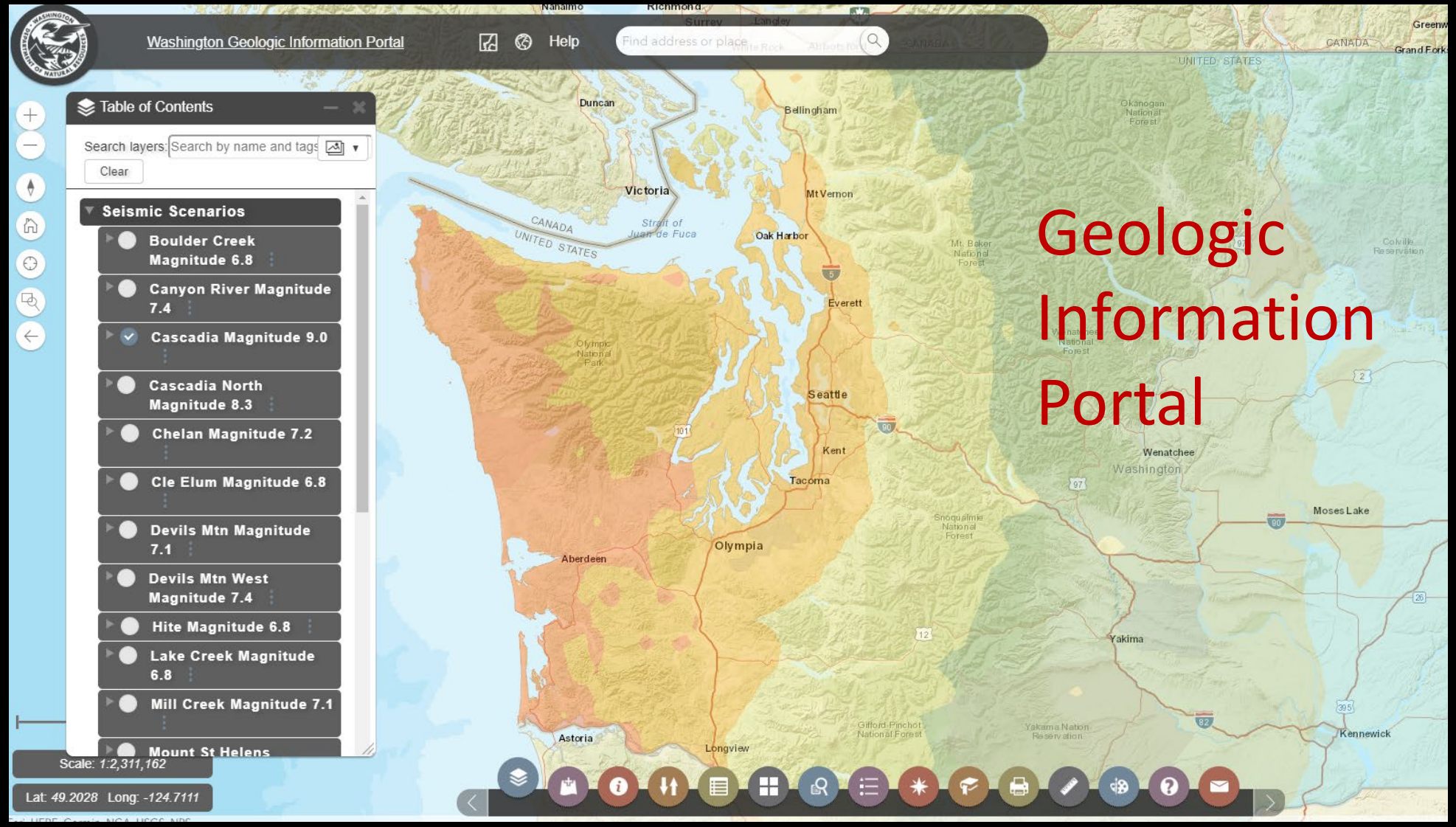
Earthquake Magnitude	Energy Release (Millions of Erg
0	63
1	20,00
2	630,00
3	20,000,00
4	630,000,00
5	20,000,000,00
6	630,000,000,00
7	20,000,000,000,00
8	630,000,000,000,00
9	20,000,000,000,000,00
10	630,000,000,000,000,00

*For each unit increase in magnitude, the energy release
SOURCE: U.S. Geological Survey.



Seismic Scenarios Catalog

Shows expected ground shaking from different earthquake sources in Washington

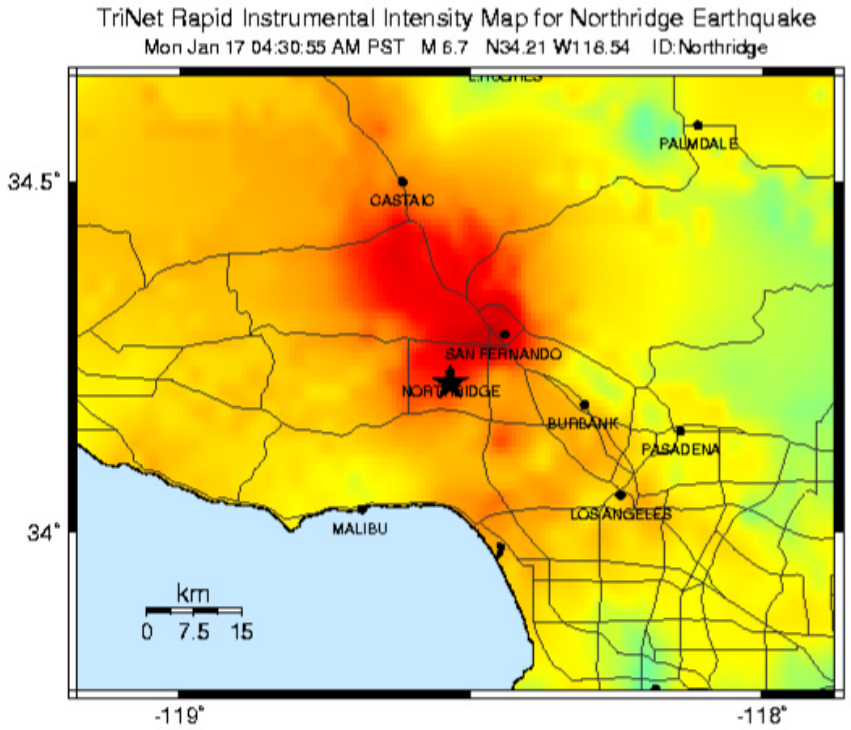


Principal Earthquake Hazards

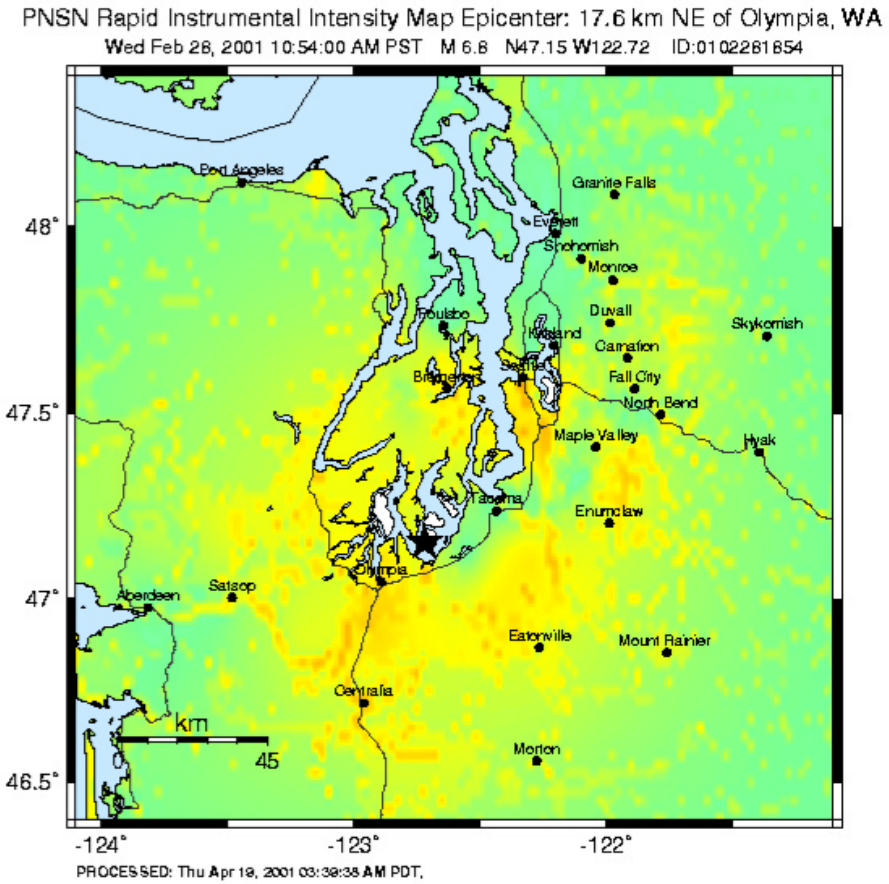
- Ground shaking
- Ground failure (cracks and offsets)
- Landslides, avalanches, mudflows
- Liquefaction
- Subsidence
- Tsunamis
- Seiches
- Fires

Northridge earthquake 1994 –
M 6.7, 10 miles deep

Nisqually earthquake 2001 –
M 6.8, 32 miles deep



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+



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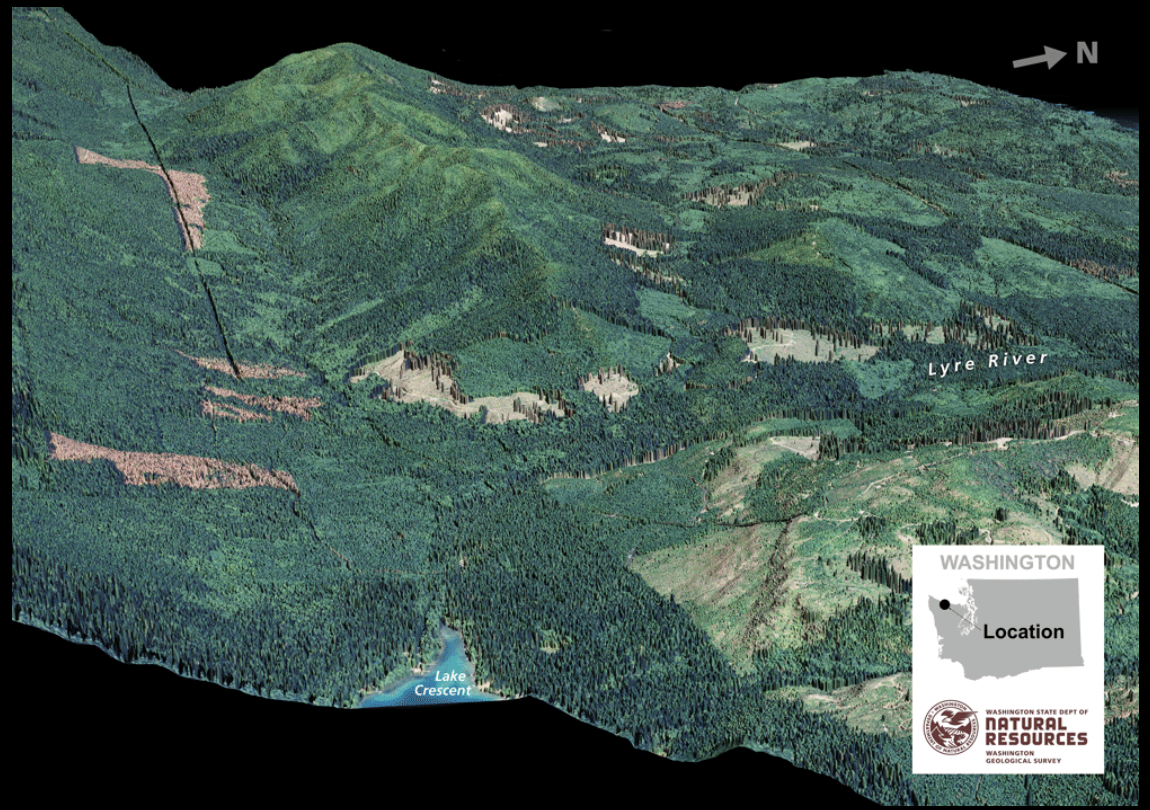
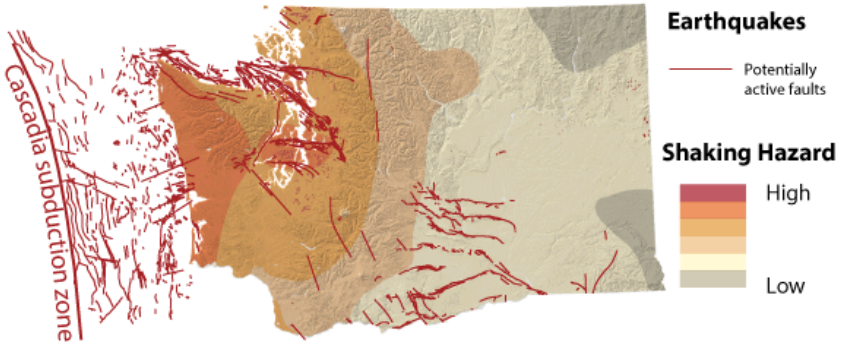
Scope of WGS earthquake program

- Map geology and faults
- Provide information through publications and on our website and portal
- Collect and distribute geophysical data to support geologic mapping



Earthquakes and Faults



This map shows areas of seismic risk from high (red) to low (grayish-green) and is from a 2007 report on the seismic design categories in Washington. Clicking on the map will download the publication.

Earthquakes occur nearly every day in Washington. Most are too small to be felt or cause damage. Large earthquakes are less common but can cause significant damage to the things we count on in everyday life, such as buildings, roads, bridges, dams,

[Read more]

- WHAT WE DO
- WHAT TO DO BEFORE, DURING, AND AFTER AN EARTHQUAKE
- ACTIVE FAULTS AND FUTURE EARTHQUAKES
- WHAT ARE FAULTS AND EARTHQUAKES?
- HOW EARTHQUAKES CAUSE DAMAGE
- HISTORIC EARTHQUAKES IN WASHINGTON

CONTACT US

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Corina Forson
Chief Hazards Geologist
360-902-1455
email

PUBLICATIONS

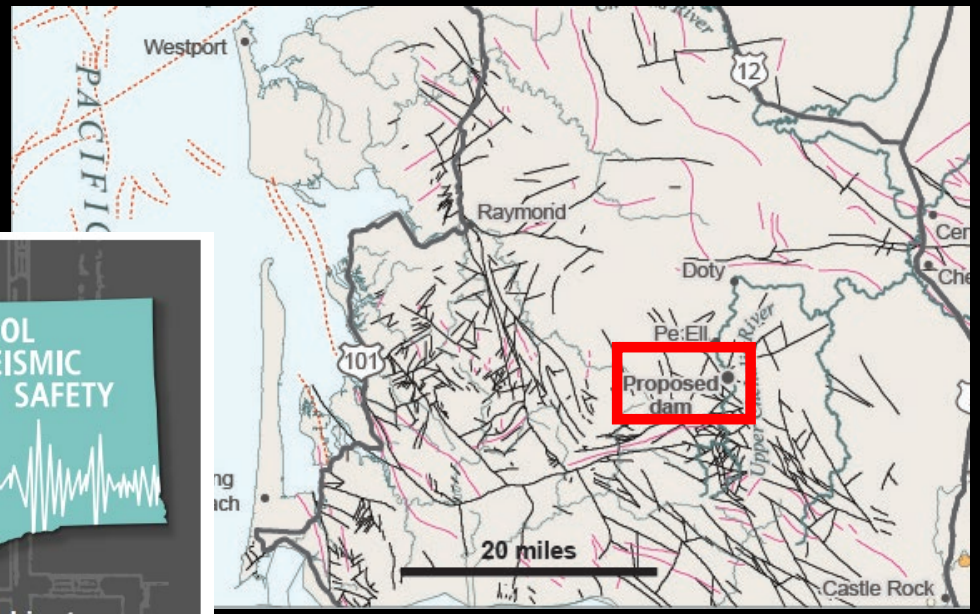
Cascadia subduction zone earthquakes
—A magnitude 9.0 earthquake scenario

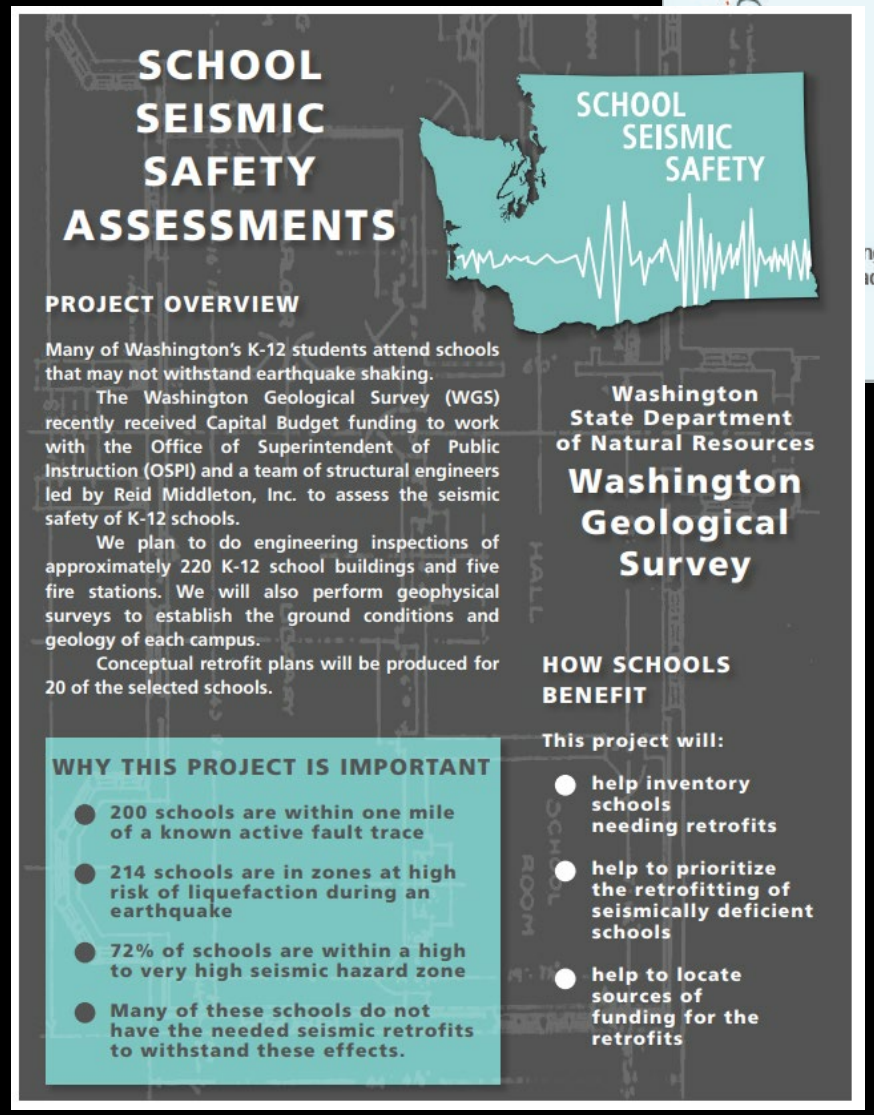
LINKS

For more information about earthquakes, faults, and emergency preparation, consider visiting the following sites:

Current projects and funding

- Studying the Doty fault to understand seismic hazard for a proposed dam near Chehalis, WA
  - Funded by the State
- Washington School Seismic Safety Project
  - Funded by the State
- Seismic monitoring
- Earthquake impact analysis for Clark County, WA (joint project with Oregon's geological Survey)
  - Funded by DOGAMI





SCHOOL SEISMIC SAFETY ASSESSMENTS

SCHOOL SEISMIC SAFETY

PROJECT OVERVIEW

Many of Washington's K-12 students attend schools that may not withstand earthquake shaking.

The Washington Geological Survey (WGS) recently received Capital Budget funding to work with the Office of Superintendent of Public Instruction (OSPI) and a team of structural engineers led by Reid Middleton, Inc. to assess the seismic safety of K-12 schools.

We plan to do engineering inspections of approximately 220 K-12 school buildings and five fire stations. We will also perform geophysical surveys to establish the ground conditions and geology of each campus.

Conceptual retrofit plans will be produced for 20 of the selected schools.

Washington State Department of Natural Resources

Washington Geological Survey

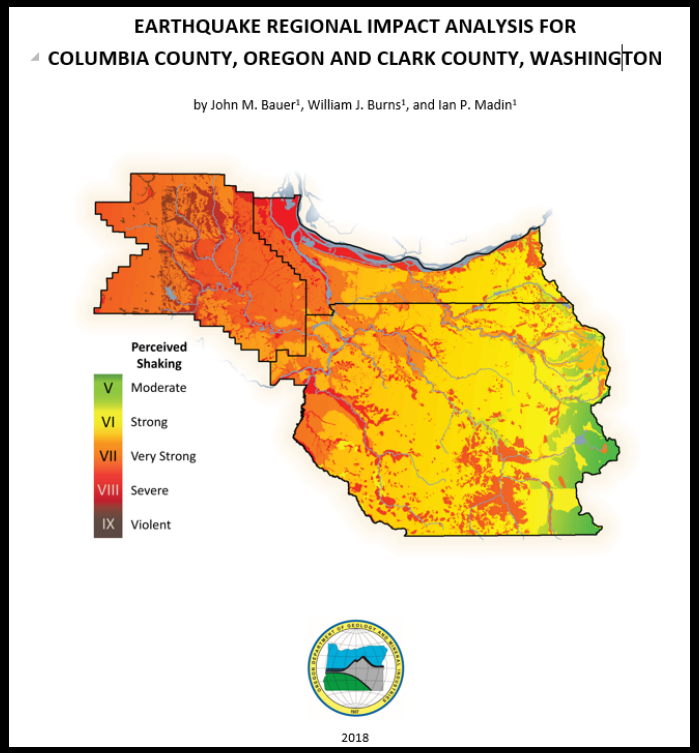
WHY THIS PROJECT IS IMPORTANT

- 200 schools are within one mile of a known active fault trace
- 214 schools are in zones at high risk of liquefaction during an earthquake
- 72% of schools are within a high to very high seismic hazard zone
- Many of these schools do not have the needed seismic retrofits to withstand these effects.

HOW SCHOOLS BENEFIT

This project will:

- help inventory schools needing retrofits
- help to prioritize the retrofitting of seismically deficient schools
- help to locate sources of funding for the retrofits



EARTHQUAKE REGIONAL IMPACT ANALYSIS FOR COLUMBIA COUNTY, OREGON AND CLARK COUNTY, WASHINGTON

by John M. Bauer[1], William J. Burns[1], and Ian P. Madin[1]

Perceived Shaking
V Moderate
VI Strong
VII Very Strong
VIII Severe
IX Violent

2018

FEMA projects

- Riskmap and Hazus
- Community and risk engagement
- New- tsunami mapping for the Columbia River

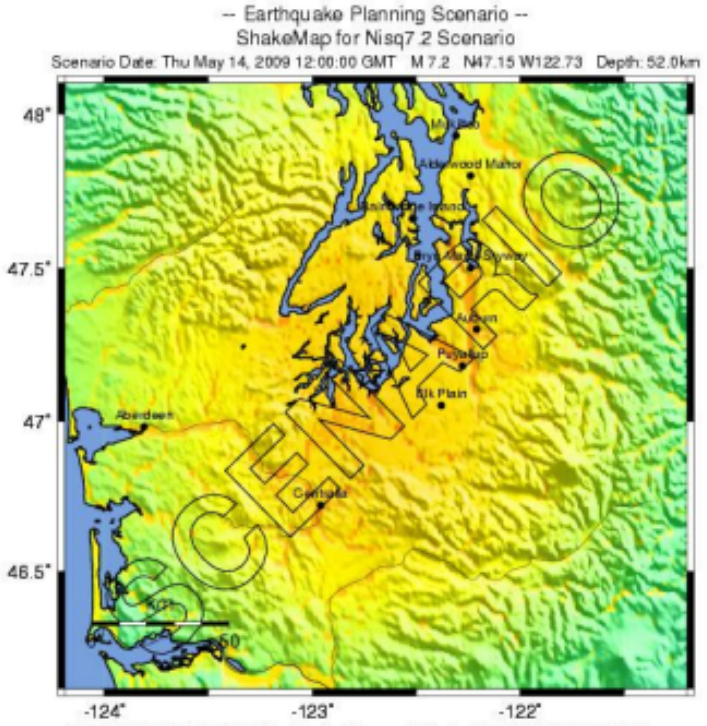
UNDERSTANDING EARTHQUAKE HAZARDS IN WASHINGTON STATE

Modeling a Magnitude 7.2 Earthquake on the Nisqually Fault Zone near Olympia, Washington

Geologic Description

This scenario is based on a M7.2 deep earthquake centered below the Nisqually delta. Deep earthquakes—also called intraplate or Wadati-Benioff zone earthquakes—are common in western Washington. Over the last 65 years, the largest of these deep earthquakes occurred between Olympia and Seattle in 1949 (M7.0), 1965 (M6.5), and 2001 (M6.8).

Intraplate earthquakes usually are the result of normal faulting within the upper part of a subducting oceanic plate and typically are not followed by large aftershocks. Beneath western Washington, the depth range of deep earthquakes begins near 30 kilometers (19 miles) and continues downward to about 60 kilometers (37 miles). This range is where all of the damaging deep earthquakes have been located. In some places, notably central and northern Puget Sound, a few events have been located much deeper, but their magnitudes tend to be small. The distribution of deep earthquake allows seismologists to map the surface of the subducting Juan de Fuca plate as it descends into the mantle below western Washington.



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INSTRUMENTAL INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1. ShakeMap for a M7.2 deep earthquake on the Nisqually fault zone near Olympia, Washington.

Tsunami Hazards- Seattle fault inundation in Tacoma

WASHINGTON STATE DEPARTMENT OF Natural Resources
Peter Goldmark – Commissioner of Public Lands
Division of Geology and Earth Resources
David A. Norman, State Geologist

NOAA Center for Tsunami Research
Pacific Marine Environmental Laboratory

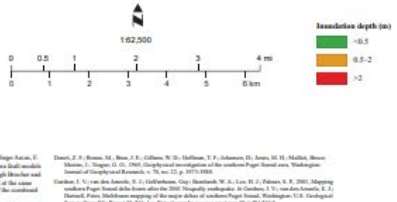
WASHINGTON DIVISION OF GEOLOGY AND EARTH RESOURCES
OPEN FILE REPORT 2009-9
Tsunami Hazard Map of Tacoma, Washington
July 2009

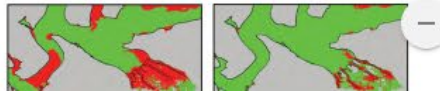
Tsunami Hazard Map of Tacoma, Washington: Model Results for Seattle Fault and Tacoma Fault Earthquake Tsunamis

by
Timothy J. Walsh[1], Diego Arcas[2], Angie J. Venturato[2], Vasily V. Titov[2], Harold O. Mofjeld[2], Chris C. Chamberlin[2], and Frank I. González[2]
[1]Washington Division of Geology and Earth Resources, PO Box 47007, Olympia, WA 98504-47007; tim.walsh@dnr.wa.gov
[2]NOAA Center for Tsunami Research, NOAA/PMEL-UW/JISAO, 7600 Sand Point Way NE, Seattle, WA 98115

Modeled Inundation from a Seattle Fault Tsunami

Modeled Inundation from a Tacoma Fault (left) and a Tacoma–Rosedale Fault (right) Tsunami





ABSTRACT

Numerical modeling of tsunamis generated by earthquakes on the Seattle fault and the Tacoma fault show that Tacoma would be subjected to larger and more damaging waves from a Seattle fault earthquake, even though the Seattle fault is considerably more distant. This is because the Seattle fault traverses Puget Sound in much deeper water and can therefore displace more water. The results show that a repeat of the Seattle fault earthquake of about A.D. 935 would generate inundation depths of more than 2 m in much of the Puyallup delta. Although the Port of Tacoma has experienced substantial dredging and filling, there is still natural ground along the main stem of the Puyallup River in Fife and in Hylebos Waterway. Both of these channels have significant areas with modeled inundation depths of more than 5 m for a Seattle fault event and more than 4 m from a Tacoma fault event. These models will provide useful guidance for paleoseismology investigations of A.D. 935 tsunami deposits and perhaps also tsunami deposits from the last Tacoma fault earthquake, which was also about 1000 years ago but is less well constrained.

INTRODUCTION

In 1995, Congress directed the National Oceanic and Atmospheric Administration (NOAA) to develop a plan to protect the West Coast from tsunami-generated loads. A panel of representatives from NOAA, the Federal Emergency Management Agency (FEMA), the U.S. Geological Survey (USGS) and the five Pacific Coast states wrote the plan and submitted it to Congress, which created the National Tsunami Hazard Mitigation Program (NTHMP) in October of 1996. The NTHMP is designed to reduce the impact attributed by T. M. Brocher, T. L. Pratt, R. L. Sherrod, and C. S. Weaver of the USGS and Diego Arcas, F. I. González, H. O. Mofjeld, V. V. Titov, and A. J. Venturato of NOAA. Details of the Tacoma fault models are given in Venturato and others (2007). These scenarios were modeled separately, although Brocher and others (2004) and Sherrod and others (2004) suggest that the two faults may have ruptured at the same time. If both ruptures were part of the same event, however, reproducing the kinematics of the combined event would be beyond the scope of this study.

The Seattle fault, which traverses much deeper water, produces significantly more inundation than either Tacoma fault scenario because it displaces much more water. This scenario is therefore shown at a larger scale.

The computed tsunami inundation is shown on the map in three color-coded depth ranges for the Tacoma fault scenarios: 0–0.5 m, 0.5–2 m, and greater than 2 m. These depth ranges were chosen because they are approximately knee-high or less, knee-high to head-high, and more than head-high. The model for the Seattle fault additionally shows a >5 m inundation depth. Figure 3 shows water heights and arrival times for all three scenarios at key locations throughout the map area.

The limit of tsunami inundation is the landward edge of the green zone. In previous maps, we have shown only the edge of inundation. Figure 4 also shows current velocities in two zones—less than or greater than 1.5 m/sec (~5 m/sec), which is the current speed at which it would be difficult to stand.

Initial flooding on the Tacoma zone occurs 15 to 20 minutes after tsunami generation for both the Seattle and Rosedale scenarios and about 5 minutes after generation for the Tacoma fault scenario (Fig. 3, Venturato and others, 2007).

DISCUSSION

There have been no investigations that have identified paleotsunami deposits in the Tacoma area. Model

Dasiel, J. P., Brown, M., Bear, J. E., Gillmore, W. D., Hoffman, T. F., Johnson, D., Jones, M. H., Mullen, Bruce Thomas, L., Teague, G. O., 1969, Geophysical investigation of the southern Puget Sound area, Washington: Journal of Geophysical Research, v. 74, no. 22, p. 5171-5188.

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Grosser, H. D., 1978, Tectonic map of the Puget Sound region, Washington, showing locations of faults, principal folds, and large-scale Quaternary deformation: U.S. Geological Survey Open-File Report 78-426, 22 p., 1 plate, scale 1:250,000.

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Jacoby, G. C., Williams, P. L., Buckley, B. M., 1992, Tree ring correlation between prehistoric landslides and abrupt tectonic events in Seattle, Washington: Science, v. 258, no. 5088, p. 1621-1623.

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Johnson, S. Y., Dadisman, S. V., Childs, J. R., Stanley, W. D., 1999, Active tectonics of the Seattle fault and central Puget Sound, Washington—Implications for earthquake hazards: Geological Society of America Bulletin, v. 111, no. 7, p. 1042-1053, 1 plate.

Kimball, J. P., 1897, Physiographic geology of the Puget Sound basin [in 2 parts]: American Geologist, v. 19, no. 5, p. 323-337 [part 1], v. 19, no. 6, p. 384-322 [part 2].

Johnson, S. Y., Johnson, A. M., Fleck, R. F., Sherrod, B. L., Dzurisin, D., Nelson, A. R., 2004, Late Holocene vertical tectonic deformation along the Seattle fault zone in Bainbridge Island, Washington: Geological Society of America Bulletin, v. 116, no. 1/2, p. 1053-1070.

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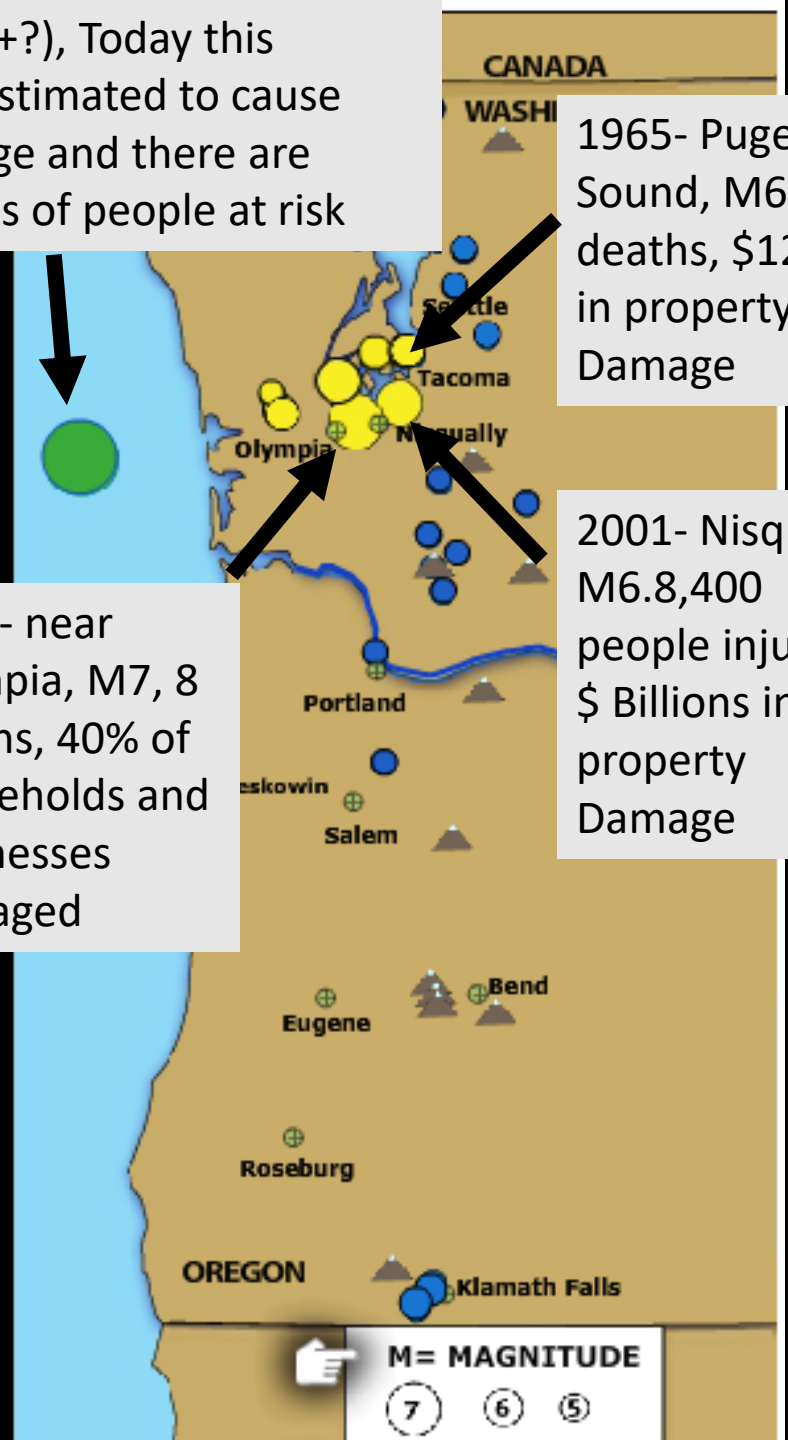
Pierce County Questions

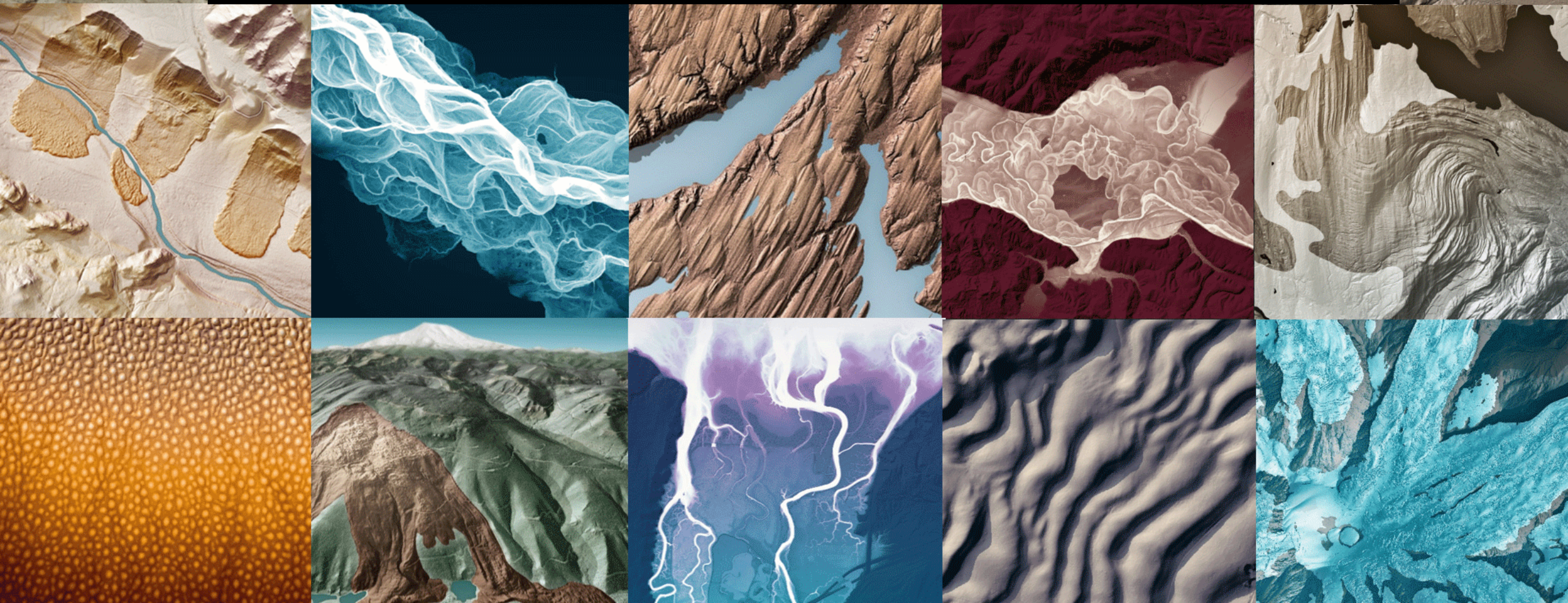
1. What are some notable incidents where this hazard occurred in our jurisdiction? The region?
2. What is our vulnerability to this hazard in terms of:
1. People? Citizens and responders (physical and psychological)
2. Property, facilities, infrastructure?
3. Delivery of services?
4. Environment?
5. Economic?



1700- CSZ, M9(+?), Today this earthquake is estimated to cause ~$49B in damage and there are many thousands of people at risk

1965- Puget Sound, M6.5, 7 deaths, $12 M in property Damage

2001- Nisqually, M6.8,400 people injured, $ Billions in property Damage

1949- near Olympia, M7, 8 deaths, 40% of households and businesses damaged

Thank you for your interest in this topic. Questions?